NACA

RESEARCH MEMORANDUM

FLIGHT INVESTIGATION OF A SMALL SIDE-LOCATED CONTROL STICK USED WITH ELECTRONIC CONTROL SYSTEMS IN A FIGHTER AIRPLANE

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON

March 11, 1957
Declassified February 10, 1959

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

A flight investigation was made to obtain pilots' opinions on the suitability of using a small stick mounted at the end of an arm rest at the pilot's side as the maneuvering flight controller for a fighter airplane. The stick used was about 4 inches long and was pivoted at the bottom. Simple springs were used to provide centering and feel to the stick. The side-located control stick was used with both a rate automatic control system and an irreversible electronic power control system. Included in the flying were take-offs, landings, stall approaches, cruising, simulated air-to-air tracking, and aerobatics.

None of the 14 pilots who used the side-located control stick reported any difficulty in flying or controlling the airplane. Furthermore, the pilots were able to do precision flying such as tracking a nonmaneuvering or mildly maneuvering target with good accuracy. In the pilots' opinion the controller was comfortably located and comfortable to use. The stick motions required were natural and the pilots became accustomed to the controller quickly. The pilots preferred to move the stick with finger and wrist motions rather than arm motions. A significant reduction of physical effort from that required for a conventional control stick resulted from use of the side-located controller. From a comfort and precision control standpoint the arm rest was considered to be essential.

INTRODUCTION

This paper describes results of a flight investigation in which a small stick (about 4 inches long) mounted at the end of an arm rest at the pilot's side was used as the airplane maneuvering flight controller. The airplane used was a Navy fighter and the side-located controller was

used with an irreversible electronic power control system and a rate automatic control system which is described in reference 1.

Recently consideration has been given to use of side-located control sticks as the primary flight controller for airplanes. Among the reasons for the interest in side-located controllers is that the space in the center of the cockpit is made available for other equipment such as radar or other flight displays. A number of automatic pilots have utilized side-located controllers somewhat similar to the one used in the present program. In general, these automatic pilots allowed only limited maneuvering at slow rates and the controllers were used more as trimming devices rather than as maneuvering controllers. With the systems used in the present investigation, rapid and universal maneuvering are possible, and the main purpose of the flight program was to determine whether a controller of the type used would be satisfactory for rapid maneuvering and for other flight operations which a fighter airplane might be required to perform. Another purpose of the flight program was to obtain information on controller feel characteristics. The evaluation of the controller has been based almost entirely on pilots' opinions.

SYMBOLS

h_p	pressure altitude, ft
M	Mach number
n	normal acceleration, g units
V_i	indicated airspeed, knots
α	angle of attack, deg
β	angle of sideslip, deg
δ_{a_T}	total aileron deflection, deg
δ_{c_l}	side-located control stick deflection, lateral, deg
δ_{c_p}	side-located control stick deflection, fore and aft, deg
δ_e	elevator deflection, deg
δ_r	rudder deflection, deg

$\dot{\theta}$ pitching velocity, radians/sec

$\dot{\phi}$ rolling velocity, radians/sec

$\ddot{\phi}$ rolling acceleration, radians/sec^2

$\dot{\psi}$ yawing velocity, radians/sec

ω circular frequency, radians/sec

DESCRIPTION OF AIRPLANE, CONTROLLER, AND CONTROL SYSTEMS

Airplane

The airplane used was a Navy fighter with an unswept wing and a turbojet engine. A photograph of the airplane is presented in figure 1 and a two-view drawing of the airplane is shown in figure 2. General dimensions and characteristics of the airplane are listed in table I. The wing-tip fuel tanks were on the airplane for all flights but no fuel was carried in them. A hydraulic booster system, which provides a boost ratio of approximately 37:1, is incorporated in the aileron control system of the airplane and a spring tab is used in the elevator control system. The rudder control system is of the conventional manual type.

Controller

The side-located control stick used was $4\frac{1}{4}$ inches long and 3/4 inch in diameter. It was pivoted at the bottom and mounted at the end of an arm rest at the pilot's right side. Photographs of the controller installation are shown in figure 3. Figure 3(a) shows the manner in which the stick was held by the pilots. The pilots preferred to operate the stick with finger and wrist motions rather than arm motions and they held the stick about $2\frac{1}{2}$ to 3 inches above the pivot point. Longitudinal or lateral motions of the control stick generate electrical signals proportional to the stick deflection and these signals are introduced directly into the elevator or aileron servo amplifiers. The maximum stick deflections are approximately $\pm 30^\circ$ longitudinally and $\pm 40^\circ$ laterally. Springs were used to provide centering and feel to the control stick, and springs which provided different force gradients were used. Figures 4(a) and 4(b) show the variations of longitudinal stick force with stick deflection for two of the springs used. Similar data for lateral stick motions are presented in figures 5(a) and 5(b). The data presented in figures 4 and 5 are from ground measurements and were obtained as the stick was moved

slowly. As noted in the figures, the forces are for a 2.75-inch moment arm which corresponds approximately to the point at which the pilots held the stick.

Inspection of figures 4 and 5 shows the forces associated with the side-located controller to be very light in comparison with those usually present with conventional control sticks. A discussion of the controller deflections and forces in terms of the airplane response is given in the section "Tests, Results, and Discussion."

Control Systems

Rate automatic control system.- Except for the controller, the rate automatic control system was the same one used in the program described in reference 1. Briefly, with this system the airplane steady-state pitching or rolling velocities are proportional to the longitudinal or lateral control stick deflections and, further, the static sensitivities between angular velocity and stick deflection are independent of the airplane flight condition. For control-free (hands-off) flight the rate automatic control system attempts to regulate the airplane angular velocities to zero. In both pitch and roll the static sensitivities between airplane angular velocity and control stick deflection could be varied and information on the sensitivities used are presented in a later section of the report. Also, in roll, a nonlinear variation of steady-state rolling velocity with lateral control stick deflection was used. With this nonlinear system the static sensitivity was reduced for small controller deflections.

Irreversible power control system.- The elevator and aileron irreversible power control systems utilized the electrical servo loops of the rate automatic control system. A block diagram applicable to both the elevator and aileron control system is shown in figure 6. In the elevator channel the electrical servomotor drove the elevator and in the aileron channel the electrical servomotor actuated the input of the hydraulic booster unit in the airplane lateral control system.

With the power control systems the static sensitivities between the elevator or aileron deflections and controller deflections could be varied. The sensitivities used are presented in a later section of the paper. A nonlinear variation of aileron deflection with controller deflection, which provided reduced sensitivity for small controller deflections, was also used.

Frequency-response data for the longitudinal and lateral power control systems in terms of elevator and aileron deflections for outputs and control stick deflections for inputs as obtained in flight are presented in figures 7(a) and 7(b), respectively. These frequency-response data were

obtained by making frequency analyses of near step control stick deflections and of the resultant elevator and aileron motions. The transient responses were obtained in flight at a Mach number of about 0.60 and an altitude of 10,000 feet. A Coradi harmonic analyzer was used to perform the analyses. A description of the Coradi harmonic analyzer is given in reference 3.

From figure 7(a) the resonant frequency of the longitudinal control system can be seen to be slightly greater than 2 cycles per second which is the natural frequency of the servo loop. The lateral control system, figure 7(b), has higher damping than the longitudinal control system as is indicated by the lack of a peak in the amplitude-ratio curve and the larger phase shifts present in the frequency-response data for the lateral control system, figure 7(b).

When the elevator and aileron power control systems were used the rudder control system was, for most flights, the same as with the rate automatic control system, which in turn was the same as that of the attitude control system described in reference 2. A rate gyro provided increased damping in yaw to the airplane and a pendulum was used to regulate the lateral acceleration to zero. When take-offs were made using the irreversible power control systems, the airplane conventional rudder control system was used.

INSTRUMENTATION

NACA recording instruments, which measured the following quantities, were installed in the airplane:

Normal, longitudinal, and transverse accelerations

Pitching, rolling, and yawing velocities and accelerations

Airspeed and altitude

Elevator, aileron, and rudder positions

Elevator, aileron, and rudder servo positions

Angle of attack and sideslip angle

Pitch and bank attitude angles

Longitudinal and lateral side-located control stick positions

The airspeed head, which was used to measure airspeed and altitude, was mounted on a boom which extended out of the nose of the airplane. (See fig. 1.) No calibration was made of the airspeed installation; therefore, the airspeed and altitude data presented in this paper have not been corrected for position error. It is estimated that the error in the measured static pressure due to the fuselage pressure field is about 2 percent of the impact pressure at low angles of attack. The airplane angle of attack and sideslip angle were measured with vanes which also were mounted on the nose boom.

TESTS, RESULTS, AND DISCUSSION

The pilots evaluated the side-located controller by using it to perform test maneuvers such as gradual and rapid pull-ups and rolls and windup turns at various airspeeds and altitudes. Also, the controller was evaluated during various flight operations as, for example, take-offs, landings, stall approaches, air-to-air tracking, rough air flying, and aerobatics (chandelles, loops, barrel rolls, etc.). Except for the take-offs, the flight maneuvers and operations were performed when both the rate automatic control system and the irreversible power control system were used. Take-offs were made only with the power control system. For the take-offs, the rudder servo actuator was disconnected and the pilot used the airplane conventional rudder control system. The maximum test altitude was approximately 36,000 feet and the maximum test Mach number was approximately 0.8.

No detailed evaluation of the rate automatic control system is given in this paper since this has been done previously in reference 1. The emphasis in this paper is placed on the pilots' opinions of the side-located controller.

Fourteen experienced test pilots flew the airplane using the side-located controller. Five were Navy pilots, three were Air Force pilots, one was an industry pilot, and five were NACA pilots. Except for one NACA pilot who had 20 flights with the equipment, the other pilots had from one to three flights.

Longitudinal Control and Response Characteristics

Rate automatic control system.- As has been stated earlier in the paper, except for the controller, the rate automatic control system used was the same as that described in reference 1. Transient responses in pitch for the combination of the airplane and rate control system for near step inputs are presented in reference 1. Also presented in reference 1 are frequency-response data. Since the response data presented

in reference 1 were obtained with the same airplane and control system as used in the present program, these response data are not duplicated in this report. The static sensitivity between airplane pitching velocity and side-control stick deflection and force were, however, different than in the tests reported in reference 1. For the tests reported in reference 1, a center-located stick was used. With the side-control stick the static variation of airplane pitching velocity with stick deflection was essentially linear and the static sensitivity had a value of 0.072 radian per second per degree. This static sensitivity is independent of airspeed. The stick deflection per g and the stick force per g (with a simple spring feel system) are therefore inversely proportional to the airspeed. At a Mach number of 0.6 and an altitude of 10,000 feet, the stick deflection per unit of acceleration is 7.2° per g, and full stick deflection of 30° will produce an increment in normal acceleration of about 4g. Using the values of static sensitivity given above and the stick-force—stick-deflection data presented in figure 4, estimates can be made of the stick force per unit normal acceleration.

The force-deflection characteristics of figure 4(a) were used only for a few flights and only one pilot flew the airplane with these controller characteristics. Most of the flights were made when using the stick-force—stick-deflection characteristics shown in figure 4(b), and all 14 pilots flew when using these controller characteristics. The force gradient through neutral was about 12 times larger with the feel system of figure 4(b) than with the feel system of figure 4(a). For increasing stick deflections greater than about 10° the stick-force gradient decreased rapidly. This rapid decrease in force gradient was unintentional and the springs which provided these feel characteristics were first used for reasons of expediency. From flight tests it was found that the nonlinear force gradient was not noticeable to the pilots; since the pilots had no objections to the nonlinear force gradient, no attempt was made to provide more linear force characteristics. It should be noted that most of the maneuvering was done within the linear range of the feel system and that not all of the pilots flew in the nonlinear range. From figure 4(b) it can be seen that appreciable friction was present, the friction band in terms of stick force being about 0.7 to 1.5 pounds depending upon the stick deflection.

As previously noted, the stick deflection per unit acceleration is 7.2° per g at a Mach number of 0.6. Using this value of stick deflection per g and referring to figure 4(b), the stick force per unit of acceleration can be seen to be about 2.0 pounds per g for slowly increasing pull-ups. This value of force per g is applicable only to incremental accelerations of 1.5g.

In the pilots' opinion with the force-deflection characteristics of figure 4(b), the airplane control and feel characteristics were satisfactory.

Irreversible power control system.- Figure 8 shows time histories of rapid pull-ups made at various speeds and altitudes when using the side-located controller in conjunction with the longitudinal power control system. In these maneuvers the control stick was moved aft in near step inputs. These time histories are presented to illustrate the control-system response and the airplane response since the pilots' opinions of the controller are associated closely with the responses resulting from controller deflections and forces. For these maneuvers the static sensitivity between elevator deflection and controller deflection based on ground measurements was 0.28. In flight the static sensitivity was considerably less than this value and decreased with increase in dynamic pressure. At a Mach number of 0.6 and altitude of 11,000 feet (fig. 8(b)), the static sensitivity was about 0.11. The decrease in static sensitivity occurred because the servo actuator was located near the cockpit at a considerable distance from the elevator; therefore, the flexibility of the control system reduced the elevator deflection per unit of servo actuator rotation. Also, the spring tab in the airplane elevator control system caused a reduction in static sensitivity to occur as the dynamic pressure increased.

By referring to figure 4(b) (only the feel system documented in figure 4(b) was used with the power control system), the forces associated with the maneuvers of figure 8 can be obtained. At a Mach number of 0.6 and an altitude of 11,000 feet (fig. 8(b)), the steady stick deflection per unit of acceleration is about 6.2° and the force per unit acceleration is about 1.6 pounds per g.

If the control system had been infinitely rigid and the stability derivatives invariant, the elevator and stick deflections per g and the stick force per g (with a simple spring feel system) would be inversely proportional to the dynamic pressure. The effect of control system flexibility is to reduce the variation of stick deflection per g and stick force per g that occurs with change in dynamic pressure.

As was also the case with the rate control system, the pilots were of the opinion that the control and response characteristics associated with the longitudinal power control system and the side-located controller were satisfactory. Therefore, the same stick sensitivity and the same feel springs were used throughout the flight program. The sensitivity setting used allowed sufficient elevator deflections to make landings, take-offs, stalls, and to attain an increment in normal acceleration of 4g. Any dead spot in the control was of such a magnitude as to not be noticeable to the pilots. Also, the time lag of about 0.1 second between a stick motion and the ensuing control surface motion was small enough not to be noticeable to the pilots.

Lateral Control and Response Characteristics

Rate automatic control system.- Transient and frequency response data in roll for the airplane-rate automatic control system are presented in reference 1 and are not duplicated in this paper. Two stick force gradients were used in the investigation. The stick force gradient of figure 5(a) was very light with the maximum force being about 1 pound. In the opinion of the one pilot who flew with this feel system, the forces were definitely too light. The controller force gradient shown in figure 5(b) is about four times greater than that of figure 5(a) and this force gradient was used for most of the flying.

Stick sensitivities (ratio of steady rolling velocity to stick deflection) ranging from about 0.030 to 0.113 radian/sec/deg were used. With the heavier feel system it was the opinion of the pilots that the maximum usable sensitivity was about 0.07 radian/sec/deg (see fig. 9(a)) at a Mach number of 0.6 and an altitude of 10,000 feet. At higher sensitivities or higher dynamic pressures the pilots found the rolling accelerations resulting from small controller deflections and forces to be too high. This made the control feel jerky and made precision flying difficult. Although the oversensitivity at high dynamic pressures could be alleviated by decreasing the stick sensitivity, the maximum rolling velocity (for a given maximum stick deflection) would be decreased at the same time.

In order to provide a low sensitivity for precision flying and, at the same time, a high maximum rolling velocity, a nonlinear roll control system was used. This nonlinear system provided a gradient which was a minimum for small stick deflections and which increased gradually as the stick deflection increased. Figure 9(b) shows the variation of steady rolling velocity with lateral stick deflection for this nonlinear system. It was the opinion of the pilots that the smaller gradient present at small stick deflections with the nonlinear system made precision flying easier. However, some of the pilots still preferred the overall characteristics of the linear system to those of the nonlinear system. One pilot objected to the nonlinear system because when rolling fast, it was difficult to maintain a constant rolling velocity because of the high sensitivity present at large stick deflections. The result was that the airplane rolling velocity tended to oscillate about a constant value of rolling velocity. From a precision-flight standpoint, the high sensitivity at large stick deflections is probably not important because when rolling fast the pilot is not trying to perform a precision task. Nonetheless, the pilot found the airplane rolling motions uncomfortable and disconcerting since he was not intentionally causing the motions.

One pilot found high rolling accelerations to be more troublesome with the side controller than with a conventional center-located stick. Because of higher deflections and forces required of the center stick

the rate of control application tends to be considerably less than that with the side controller. Also, the pilot was of the opinion that the higher stick forces usually present with a center stick caused him to tense his muscles to apply the required force and this in turn tended to brace him against the rolling acceleration.

It is of incidental interest to mention that a head support which restrained the pilot's head in the lateral direction was used. A photograph of this head support is shown as figure 10. The pilots found the head support to be a definite aid in maneuvers involving high rolling accelerations because the support fixed the pilot's head with respect to the airplane thus keeping the head from hitting the sides of the canopy and making it easier for the pilot to observe the gun sight and other instruments.

Irreversible power control system.- Time histories of the control-system response and airplane response at various flight conditions for near step side-located control stick deflections are presented in figure 11. For the maneuvers shown in figure 11, the static sensitivity between total aileron deflection and stick deflection was about 0.77° per degree based on ground tests. Again the static sensitivity was somewhat less in flight because of control-system flexibility. At a Mach number of 0.6 and an altitude of 10,000 feet, the static sensitivity was about 0.63° per degree.

As with the rate control system, a linear and a nonlinear variation of controller output signal with lateral stick deflection was used. Since the gain of the servo system increases with increasing amplitude of input signal (see the frequency-response data in ref. 2), there is a slight unintentional nonlinearity present near neutral with the linear system. Various control stick sensitivities or gains were used. Figure 12 shows the variation of total aileron deflection and rolling velocity with lateral stick deflection for one stick sensitivity setting with both the linear and nonlinear systems. These data are for a Mach number of 0.6 and an altitude of 10,000 feet. At this flight condition with the force characteristics of figure 5(b), the gain used with the linear system was considered by the pilots to be about the maximum usable from the standpoint of control sensitivity.

Pilots' Opinions of Side-Located Controller

In this section of the report an attempt is made to give the pilots' overall opinions of the side-located controller. Since an electronic control system was being used and the reliability of such control systems has not been established, the pilots, particularly those who had only one flight, tended to be somewhat apprehensive relative to aspects of reliability when flying with the system. This factor may have influenced

the pilots' opinions. Also, it is pointed out that only one side controller located in only one position has been used. As might be expected there was not unanimity of opinion with respect to some characteristics and the majority opinion is usually given. However, specific pilot's objections are also listed.

The opinions of the pilots were obtained in post-flight interviews and by means of a questionnaire which the pilots answered at their convenience. The questionnaire with the answers from eight pilots is presented in the appendix.

Comfort and naturalness of control.- All of the pilots were of the opinion that the side-located controller was comfortably located and comfortable to use. The stick motions required were natural and the pilots became accustomed to the controller quickly.

The pilots preferred to use finger and wrist motions rather than arm motions when flying with the side controller. From a comfort and precision control standpoint, the arm rest is considered to be essential. The locations of the lateral and longitudinal trim knobs, which can be seen by referring to figure 3(a), were unsatisfactory. When trimming, pilots desire to keep a hand on the control stick and this could not be done with the test installation. No attempt was made in the program to provide satisfactory trim knob locations.

Magnitudes of forces and deflections.- Although several different controller deflection-force gradients were used in the program, no detailed effort was made to establish satisfactory or optimum ranges of controller forces and deflections. The lateral force and deflection characteristics have been discussed previously and will not be discussed again here. When the feel system having the characteristics shown in figure 4(b) was used, the longitudinal control feel and deflection characteristics and the associated airplane response were pleasing to the pilots for the ranges of flight conditions covered and for the maneuvers performed. However, several pilots expressed the opinion that the controller forces may be too light for violent maneuvering in that it may be too easy for the pilot to inadvertently cause the structural limitations of the airplane to be exceeded. The nonlinear force deflection variation (see fig. 4(b)) although probably undesirable was not noticeable to the pilots and they had no adverse comments concerning this characteristic. It should also be mentioned that the harmony of forces between longitudinal and lateral control was in the pilots' opinion satisfactory.

General flying characteristics.- The side-located controller was used for a variety of flight operations including take-offs and landings in calm air and in moderately gusty cross winds, stall approaches, simulated wave-offs, cruising in both smooth and rough air, aerobatics, and tracking. For this flying none of the pilots reported any particular difficulty in

flying or controlling the airplane with the side-located controller. Furthermore, the pilots were able to do precision flying such as tracking a nonmaneuvering or mildly maneuvering target with good accuracy.

The pilot effort required in flying was reduced when using the side-located controller. The reduced pilot effort results from light control forces and increased comfort provided by the arm rest.

It was pointed out in reference 1 that the pilots did not object to the neutral static stability (stick displacement and stick force zero for 1 g flight at any airspeed) with the rate control system for the flight operations reported therein. Since that report was written a large amount of flight time has been accummulated with the rate control system and several pilots have commented on the lack of positive static stability in 1 g stall approaches. The general opinion is that, even though the neutral static stability is not objectionable for most flight conditions, positive static stability is desirable for low-speed flight near the stall since a rearward stick travel and an increasing pull force provide stall warning to the pilot.

CONCLUDING REMARKS

A flight investigation was made to determine whether a small stick mounted at the end of an arm rest at the pilot's side would be suitable for use as a maneuvering flight controller for a fighter airplane. The stick used was about 4 inches long and was pivoted at the bottom. Simple springs were used to provide centering and feel to the stick. The side-located controller was used with both a rate automatic control system and an irreversible electronic power control system. The equipment used allowed rapid and universal maneuvering and included in the flying done with the side-located controller were take-offs, landings, stall approaches, cruising in both smooth and rough air, simulated air-to-air tracking, and aerobatics. The maximum test Mach number was about 0.8 and the maximum altitude was 36,000 feet.

For the flying done in this investigation, none of the pilots reported any particular difficulty in flying or controlling the airplane with the side-located controller. Furthermore, the pilots were able to do precision flying such as tracking a nonmaneuvering or mildly maneuvering target with good accuracy. In the pilots' opinion the side-located controller was comfortably located and comfortable to use. The stick motions required were natural and the pilots became accustomed to the controller quickly. The pilots preferred to move the stick with finger and wrist motions rather than arm motions. From a comfort and precision flying standpoint, the pilots considered the arm rest to be essential.

The longitudinal control and response characteristics were considered to be satisfactory by the pilots. At a Mach number of 0.6 and an altitude of 10,000 feet, the force per g was about 1.5 to 2 pounds for accelerations between 1 g and 2g. The force per g decreased with increase in speed. The maximum force associated with the controller was about 4 pounds.

At a Mach number of 0.6 and an altitude of 10,000 feet, the maximum usable lateral stick sensitivity, in the opinion of the pilots, was about 0.07 radian per second of rolling velocity per degree of lateral stick deflection with the rate control system and about 1.0° total aileron per degree with the power control system. This was with a maximum stick throw of 40° and a maximum stick force of about 4 pounds.

A significant reduction of physical effort from that required for a conventional control stick resulted from use of the side-located controller. The reduction in pilot effort resulted from the forces being light and also from the increased comfort associated with the arm rest.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., December 12, 1956.

APPENDIX

PILOTS' QUESTIONNAIRE

Since the evaluation of the side-located controller was based almost entirely on pilots' opinions, it was thought desirable to include the questionnaire which was answered by most of the pilots who flew the airplane equipped with the side-located controller together with the replies from eight of the pilots. The questionnaire was not prepared in time to be answered by one Air Force test pilot and the industry test pilot.

The questionnaire with the replies of eight pilots is as follows:

Questionnaire for Pilots Who Fly the NACA Airplane Equipped With the Side-Located Controller

Give a brief description of the flight listing the maneuvers performed and what flying was done.

1. Is the side-located controller comfortable to use? What equipment was worn? (Gloves, Mae West, etc.)

2. Are the stick motions required natural?

3. Was there any difficulty in becoming accustomed to the controller and how long did it take to become accustomed to it?

4. How was the stick held? Palm grip or like a pencil?

5. What trim knob location or manner of trimming would you think desirable for a controller of this type?

6. Were the response characteristics of the airplane satisfactory? In pitch? In roll? List any objections.

7. Were the control-stick force and deflection characteristics satisfactory? In pitch? In roll? List any objections such as the forces being too light or too heavy.

8. Was the harmony between the longitudinal and lateral control satisfactory? List any objections.

9. Did the side-located stick make flying easier? If so, in your opinion is this important or significant?

10. Did you like flying with the side-located controller?

11. List anything you do not like about this side-located controller or side-located controllers in general.

12. List any miscellaneous thoughts you may have about side-located controllers, such as advantages or disadvantages as compared to conventional sticks. Also list any other pertinent observations or suggestions.

Answers to Questionnaire

Pilot A:

Organization: NACA

Type of control system: Answers are based on several flights with both the rate automatic control system and the irreversible power control system.

Description of flight: Aerobatics - tracking - strafing - high- and low-speed maneuvers - landings and take-offs, also rough air flight.

1. Yes. G-suit, crash hat (gloves - yes, Mae West - yes).

2. Yes.

3. Learning time was very short - basic normal type flight was possible almost immediately.

4. Like a pencil.

5. Present pitch trim is satisfactory. Roll trim should be similar type located normal to pitch trim and located so that it could be moved with fingers without releasing grip on controller.

6. Yes. Very good response. No perceptible time lags in response.

7. The control forces are on the light side of optimum but heavier spring would not be needed in pitch as greatly as in roll, i.e.: variation of force with deflection should be greater in roll than pitch due to physiological factors. Those forces used were in acceptable range but not necessarily optimum.

8. Within tolerable limits. See answer to No. 7.

9. Easier physically. Yes, a very important factor in long flight time operations.

10. Yes. It is a natural trend for future high-performance aircraft.

11. It is a good start. Other configurations of controllers as a physical link between man and machine should be studied.

12. The side-located-controller concept is a logical trend where irreversible power control systems are to be used. Physiologically it will allow:
    a. The airman to be better secured in his seat and to the arm support.
    b. Less physical work load for a similar flight using the arm and center stick control.
    c. Better possibility of designing a pressurized environmental control capsule which will afford an easing of the present trend of "King Arthur" type full pressure suits and therefore ease the psychological burden attached to space flight.

    Too much emphasis cannot be placed on the operational aspect of designing reliability into a fully duplicate system - each of which may control in case of malfunction.

    The future controller should evolve into a device similar in physical appearance and characteristics for all types of aircraft as long as we use man as part of the control system.

Pilot B:
Organization: NACA

Type of control system: Both rate automatic control system and irreversible power control system.

Description of flight: Climbs, glides, turns, rolls.

1. The side controller was very comfortable to use. Equipment worn was gloves, Mae West, seat-type chute which did not interfere with the operation of the side controller.

2. The stick motions seem natural.

3. There was no difficulty in becoming accustomed to the operation. After about five minutes of flight, I became confident of the controller to do the job.

4. The stick is held like a pencil.

5. The trim adjustment should not be on the stick but rather be close enough so that the stick could be held and the trim adjusted with the fingers.

6. The response characteristics were pretty good but there is too much drift when flying straight and level. Above 10,000 feet the control becomes a little sensitive.

7. The forces seem about right to me.

8. The harmony seems about right to me.

9. The position of the control and the ease of operation are excellent. The good support of the arm rest makes control very good even when under acceleration.

10. Yes.

11. This installation is not integrated with the rest of the cockpit. It makes the system not as good as it could be in a production airplane.

12. The control system must be fail safe and should be made so it will not feed in any hard over signals. There must be an alternate or standby system that will switch in automatically when the normal one fails. There also must be an indicator to show this shift.

Pilot C:

Organization: NACA

Type of control system: Both rate automatic control system and irreversible power control system.

Description of flight: Maneuvers made in several flights: Pullups, slow and abrupt. Turns, in some cases to buffeting and C_N maximum. Simulated tracking. Rolls, slow and abrupt, all deflections, linear and nonlinear. Aileron and barrel rolls. Landings in both servo and rate modes, and one take-off in servo mode.

1. Yes. Gloves, Mae West, parachute, crash helmet, and mask.

2. Yes.

3. No great difficulty. Have to remind myself sometimes that I'm not just resting in an arm chair. Would take more flying than I've done to cease having to think about what I'm doing with the side-arm controller, at least from time to time.

4. Like a pencil.

5. Trim wheels as for pitch for roll and pitch both, but close to stick so can be operated with fingers of same hand as on controller.

6. Response O.K. in pitch. Prefer linear system in roll for all-round use with the force gradients existing although there is a tendency to be jerky for maneuvers requiring small deflections.

7. Satisfactory. At least I don't know what to do to improve it.

8. Harmony good.

9. Effort decreased and comfort increased considerably over a period of time, probably could be very important.

10. Yes.

11. If arm gets tired or injured can't fly with other as one could with center stick. Also not so convenient when handling charts and computers or making computations as center stick unless rate or attitude stabilization is included.

12. Most accurate job of controlling possible with finger tips, if hand can be solidly rested at the base. This best accomplished, also if don't have to move fingers, hand, or wrist very far. Would appear that perhaps a force-type finger-tip controller or combination of displacement and force controller might be optimum. The side-arm position makes it possible to fix and steady arm, wrist, and hand against undesirable forced motions.

Pilot D:

Organization: Service

Type of control system: Irreversible power control system with conventional rudder control.

Description of flight: Two take-offs and landings were accomplished on 25 July 1956 at Langley AFB, using the side-located controller. I found the entire operation quite normal and was able to maneuver the aircraft as desired. In fact, on entering the T-33 cockpit for the return flight to Baltimore, the conventional controls appeared obsolete.

1. Yes. Gloves, Mae West, etc. Only summer flying clothing was worn for the flights.

2. Yes.

3. I experienced no difficulty in becoming accustomed to the controller. However, I have flown similar controls in various types of aircraft over a period of several years.

4. The stick was held like a pencil.

5. Perhaps a hand-grip-type control, with the conventional trimmer on top of the control, would be quite acceptable. I would suggest that this type of control be evaluated at an early date.

6. The response characteristics were entirely satisfactory, with the possible exception of excessive stick travel which is required to control the aircraft in pitch when actually rotating the aircraft for either take-off or landing.

7. The stick forces appeared to be entirely acceptable. However, evaluation flights with slightly heavier forces should be explored.

8. The harmony between the longitudinal and lateral control appeared to be entirely satisfactory.

9. This is a difficult question to answer. However, it was my impression that the control of the aircraft was normal, with the possible exception of a tendency to not coordinate rudder and roll control.

10. Yes.

11. As indicated in previous questions, the side-located controller evaluated in the NACA aircraft was considered acceptable, based upon the two short flights which I performed. Prior to reaching any definite conclusions, this type of controller should be evaluated under all conditions of flight (especially strong, gusty cross-winds and turbulent conditions) and in formation flight.

12. The side controller has the definite advantage of a clear panel for instrument and interceptor flights. Also, it facilitates emergency escape. There were no obvious objections observed; however, more extensive flying is considered desirable under all conditions of flight to bring out any unsatisfactory factors that may be experienced in time.

Pilot E:

Organization: Service

Type of control system: Rate automatic control system.

1. Yes, the side-located controller was most comfortable to use. Personal equipment used during the flight was gloves, Mae West, and summer flight suit.

2. The stick motions required to accomplish the flight were natural in all respects. At first it seemed a little strange to maneuver the airplane with a stick not located in the center of the cockpit but this soon disappeared.

3. The transition to this type of controller was with a minimum of difficulty. I became accustomed to the controller in approximately 10 minutes. Thereafter at times I forgot I was using this unique system.

4. The stick controller was held somewhat like a slightly modified pencil grip.

5. The location and type of pitch trimmer was very good, however, the lateral trimmer cannot be used without abandoning one's grip on the stick controller. When this is done the possibility exists that the controller may be inadvertently bumped. I would recommend a lateral trimmer similar to the pitch trimmer and located to the right and rear of the control box.

6. The flight control response characteristics of the airplane were adequate and satisfactory for both pitch and roll. Both the linear and nonlinear system were used for lateral control. It is believed that both linear and nonlinear systems should be available for selection by the pilot. Possibly, intermediate positions of linear selection should be available. Due to lateral wallowing during approach to landing, I preferred the nonlinear system. During other than power approach configuration flight I preferred the linear system.

7. I object most strenuously to the lack of stick feel during 1 g approach to stall. A reliable stall warning system is a must unless some other source of feel is provided. I particularly liked the maneuvering stick forces gradient but I am concerned about the possibility that the airplane may be more easily overstressed.

8. Control stick harmony was good and is considered to be satisfactory.

9. I do not believe that I have had enough experience on this system to definitely say that it was easier to fly. The potential ability to reduce pilot fatigue is apparent in the control stick steering because of the arm rest and the fact that the airplane is flown by use of the fingers only. The ease of flying is not as important a criterion as the space saving abilities of the side controllers.

10. Yes.

11. The arm rest prohibited easy access to the right console especially since the air-conditioning controller in this airplane requires constant attention.

12. This concept looks very plausible to me especially since it would be so compatible with capsules. The uniform response and automatic trim (min. trim changes) characteristics are definite advantages. Since control stabilization is now required in most airplanes and autopilots are being used extensively, it is apparent that an autopilot stick controller would simplify and improve the present airplane control systems.

Pilot F:

Organization: Service

Type of control system: Rate automatic control system.

Description of flight: A 1.5 hour flight was flown in the NACA airplane by this pilot using the rate control system with the side-located control. In general, the flight consisted of following the NACA recommendations and conducting towering cumulus penetrations. Actual landings and take-offs were not conducted on this flight.

1. The side-located controller is comfortable to use. Gloves, Mae West, and summer flight suit were worn.

2. The stick motions required were quite natural and were not considered awkward in any direction.

3. This pilot became accustomed to the controller for normal aerobatic flight maneuvers within a few minutes. The controller was used to control the aircraft positively during stall maneuvers, rolls, and in flights through towering cumulus without difficulty. Response was positive and immediate.

4. The stick was held somewhat like a pencil. Pilot's middle finger could not be used because of a stitch in the knuckle but this did not handicap use of the controller.

5. The general concept and location of the pitch trimmer seemed quite good. Some refinements could probably be made to bring it slightly in better reach of the fingers while holding the stick control. The roll and yaw trimmer was a little more awkward to use and should be relocated to the right of the controller. This would prevent having to remove the hand from the controller and reach inside to trim in yaw and roll.

6. The aircraft response in pitch and roll appeared to be about maximum for the airplane. It was considered adequate. However, it should be noted that formation flight and landings were not executed.

7. The controller stick force and deflection ratio were in general quite good. However, this pilot prefers compromising between the linear and nonlinear characteristics. It was felt that although the airplane was very responsive using the linear rates that the instrument handling characteristics would be improved somewhat by slightly nonlinear scheduling. The control forces were certainly not too heavy and if any doubt exists as to their being too light it could be increased substantially without becoming too heavy. It was noted that the controller evidently did not properly center every time as a slight attitude drift would occasionally occur when the controller was released at center.

8. Longitudinal and lateral control harmony appeared satisfactory.

9. I did not consider the side-located stick substantially different from the center stick for ease of flying. However, this is based on only 1.5 hours of flight. It should be noted that in most contemporary airplanes the right knee and leg is used as an arm rest for the center-located stick so fatigue is not a problem in either location. Considering the lack of space available on the average fighter console, addition of an installation similar in size requirements to the side controller and arm rest tested here would be prohibitive. The retracting arm rest was considered extremely awkward to continually place up and down when operating items used on the right-hand console.

10. Refer to answer for No. 9.

11. Refer to answer for No. 9.

12. Refer to answer for No. 9.

Pilot G:

Organization: Service

Type of Control System: Rate automatic control system.

Description of flight: The flight was made on 30 August. A take-off was made on the normal control system and a shift was made to the rate controller while climbing through 10,000 feet. Various maneuvers were made at 30,000 feet using both the position stick (side controller) and the force stick.[1] Air-to-air tactic with another fighter and all other maneuvers within the usable limits of the airplane were done at altitude. A high Mach number dive was done to 10,000 feet where the high dynamic pressure and slow flight and stall regimes were explored. A normal landing was made using the force stick.

1. Yes. Summer leather flying gloves (Navy) and Navy Mae West.

2. Yes, however, stick deflections seemed a little high in the low speed range.

3. Very little if any - the greatest objection was the lack of force feel.

4. Like a pencil.

5. Believe the optimum stick configuration would be shaped something like a pistol grip and held in the hand. With this, trimmers could go on the stick. Having to remove the hand or fingers from the stick to trim is very undesirable.

6. Yes. The rate type of response of sensing seems good.

7. The controller forces were not too light but the stick needed damping on return to neutral. Believe the deflections may be a little high per unit pitch and roll rate.

8. Yes.

9. Yes. Believe any location such as this is more natural and less tiring to the pilot.

10. Yes, very much.

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[1]A rigid force-stick controller was also available for use in this flight. Comments on the force stick should be disregarded.

11 and 12. No objections to side-located controller concept. However, believe the next step should be a pure force stick, with no position stability, located as a side controller the stick should be grip size so that some force can be required to get response. An objection to the present arrangement is that the forces required to move the stick are very light because the stick was designed for finger-tip operation. This has the undesirable feature of allowing the pilot to introduce unintentional signals to the system by just the acts of laying hold of, or letting go of the stick.

I found the force stick superior to the position stick, which tends to verify the premise that a pilot seldom, if ever, knows what position his control stick is in; he is mostly sensitive to the force that he is exerting on the stick. In flying the force stick, I did not miss stick motion at all.

The side-mounted position stick showed up badly when recovering from full stalls. In attempting to recover from the steep dive resulting from the stall, all feel for the plane seemed to be lost. The stick required large deflections with little response. Due to this, I was very conservative on pullout, having little feel and not wanting to stall the plane on the recovery. With the force stick, I felt I had much more control and feel and was able to recover with a minimum altitude lost.

Pilot H:

Organization: Service

Type of control system: Rate automatic control system.

1. Yes, the side-located controller was comfortable to use. Pilot equipment included a summer flying suit, Mae West, and gloves.

2. Yes, stick motions were natural.

3. It was surprisingly easy to become accustomed to the side-located controller. After approximately 15 minutes of flying with the controller the pilot felt very natural about maneuvering the airplane in simulated tactical flight.

4. The stick was held much like a pencil.

5. Pitch trim is satisfactory as installed. A similar installation for lateral trim located directly aft of the stick would appear desirable.

6. Response rates of the airplane were satisfactory using both the linear and nonlinear lateral control. Response to both maximum pitch and maximum roll inputs was greater than that which would be used tactically in the airplane.

7. Controller stick force and deflection characteristics were satisfactory in both pitch and roll. The light force/g gradient is considered desirable.

8. Control harmony was good for lateral and longitudinal control.

9. Since this pilot has flown with the side controller only one flight, it cannot be said that flying was easier; however, it is considered that after a few flights it would be easier to fly with the side controller than with the conventional control stick. Certainly the fatigue during maneuvering flight is greatly reduced using the side controller.

10. Yes, in general, I liked flying the side controller.

11. Two possible disadvantages came to mind when considering side-located controllers. The locating of the controller and arm rest on the right console presents a problem with regard to finding room to relocate the instruments and controls normally located there. This pilot, during tactical air-to-air maneuvering, frequently holds the stick with the left hand and places the right hand on the windshield bow to help get turned farther around to look to the rear during a left turn. This is especially applicable when wearing a pressure suit.

12. The side-located controller would alleviate the problem of stick stowage in airplanes using the downward ejection seat.

REFERENCES

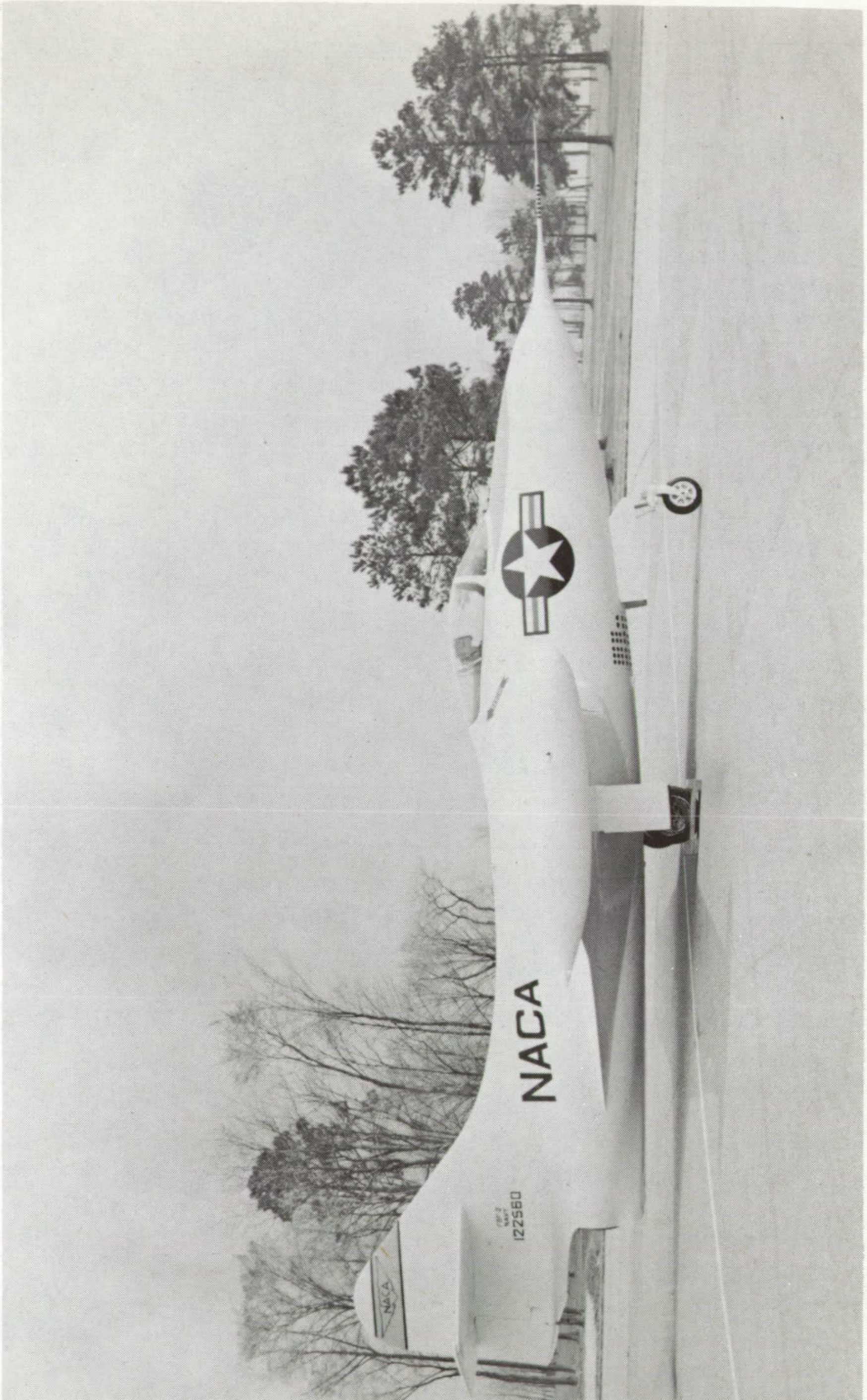
1. Russell, Walter R., Sjoberg, S. A., and Alford, William L.: A Flight Investigation of the Handling Characteristics of a Fighter Airplane Controlled Through a Rate Type of Automatic Control System. NACA RM L56F06, 1956.

2. Sjoberg, S. A., Russell, Walter R., and Alford, William L.: A Flight Investigation of the Handling Characteristics of a Fighter Airplane Controlled Through an Attitude Type of Automatic Pilot. NACA RM L56A12, 1956.

3. Eggleston, John M., and Mathews, Charles W.: Application of Several Methods for Determining Transfer Functions and Frequency Response of Aircraft From Flight Data. NACA Rep. 1204, 1954. (Supersedes NACA TN 2997.)

TABLE I.- GENERAL AIRPLANE DATA

Wing:	
Span (with tip tanks), ft	37.99
Span (without tip tanks), ft	35.25
Area (without tip tanks), sq ft	250
Airfoil section	NACA 64_1A012
Aspect ratio (without tip tanks)	4.97
Taper ratio	0.46
Incidence, deg	0
Dihedral, deg	4
Twist, deg	0
Sweep of 27-percent chord line, deg	0
Mean aerodynamic chord (M.A.C.), in.	89.45
Total aileron area, sq ft	18.44
Aileron travel, deg	19 up 14 down
Horizontal Tail:	
Span, ft	17.21
Area (including elevator), sq ft	66.20
Elevator area, sq ft	19.20
Elevator travel, deg	18 up 15 down
Tail length, 25-percent M.A.C. of wing to elevator hinge line, ft	18.45
Vertical Tail:	
Area, (not including dorsal fin), sq ft	36.02
Rudder area, sq ft	8.54
Rudder travel, deg	±26
Miscellaneous:	
Length (excluding nose boom), ft	38.13
Weight, take-off (tip tanks empty), lb	14,460
Center-of-gravity position, take-off, percent M.A.C.	26.5
Center-of-gravity position, landing (1,000 lb fuel), percent M.A.C.	28.4
Engine	J42-P-8



L-93054

Figure 1.- Side view of airplane.

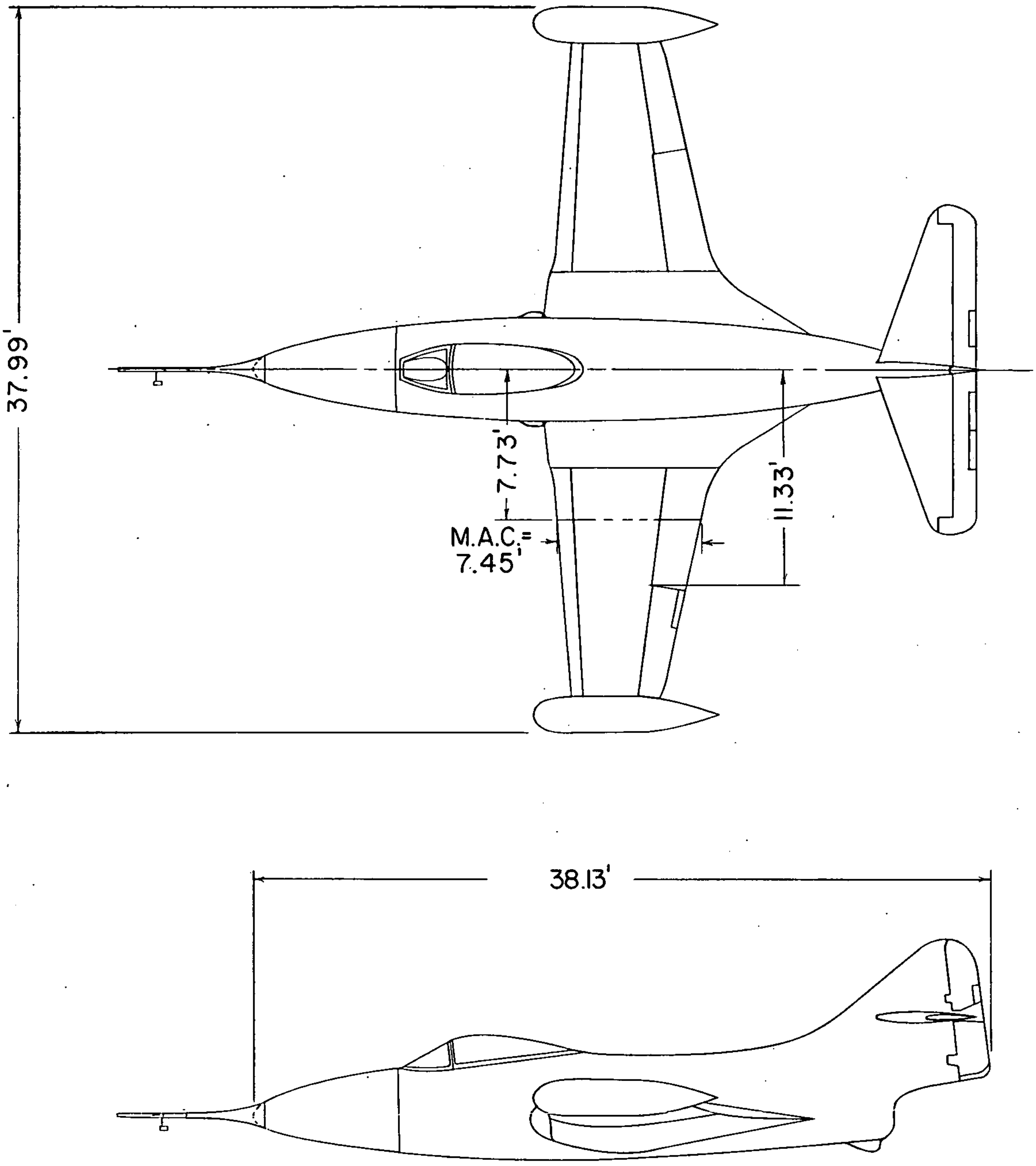
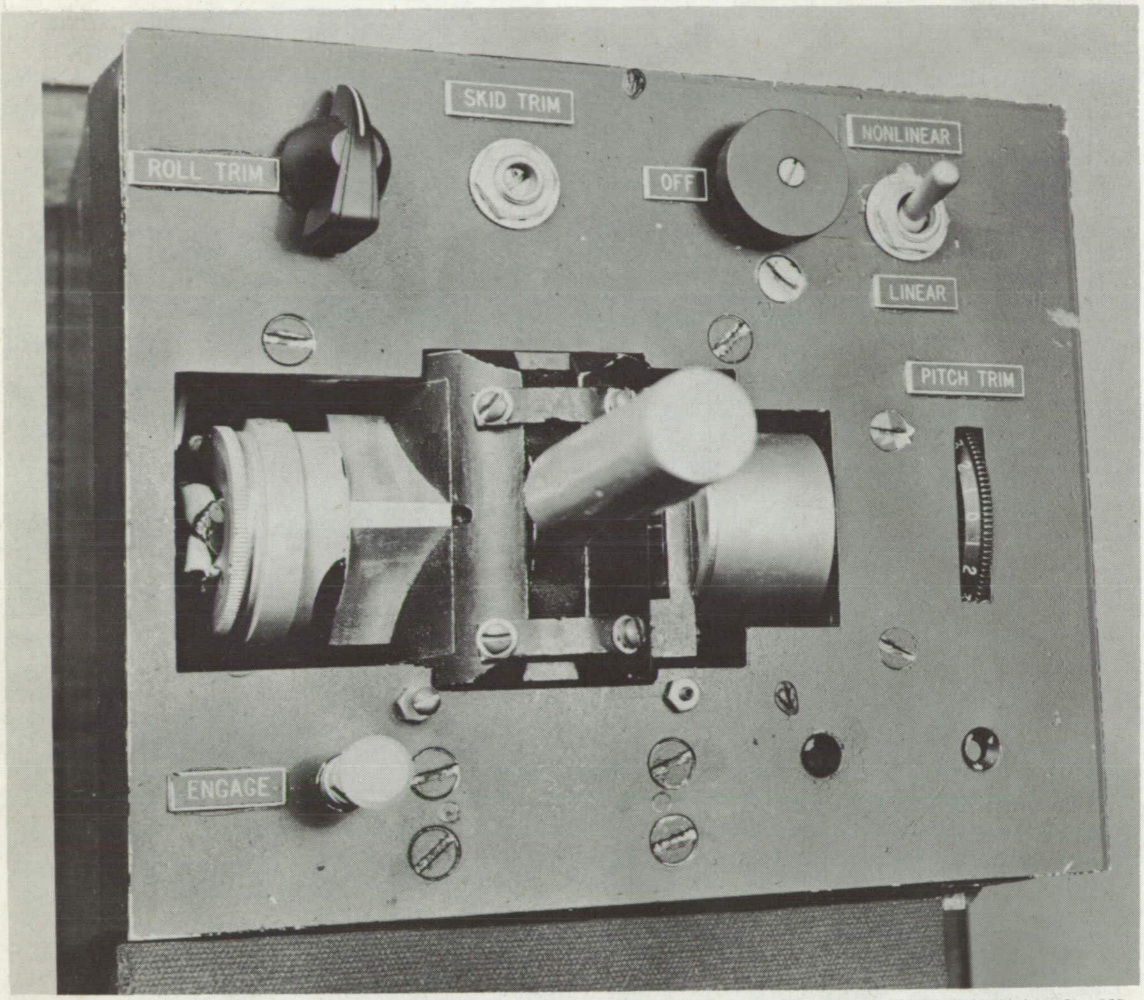


Figure 2.- Two-view drawing of airplane.

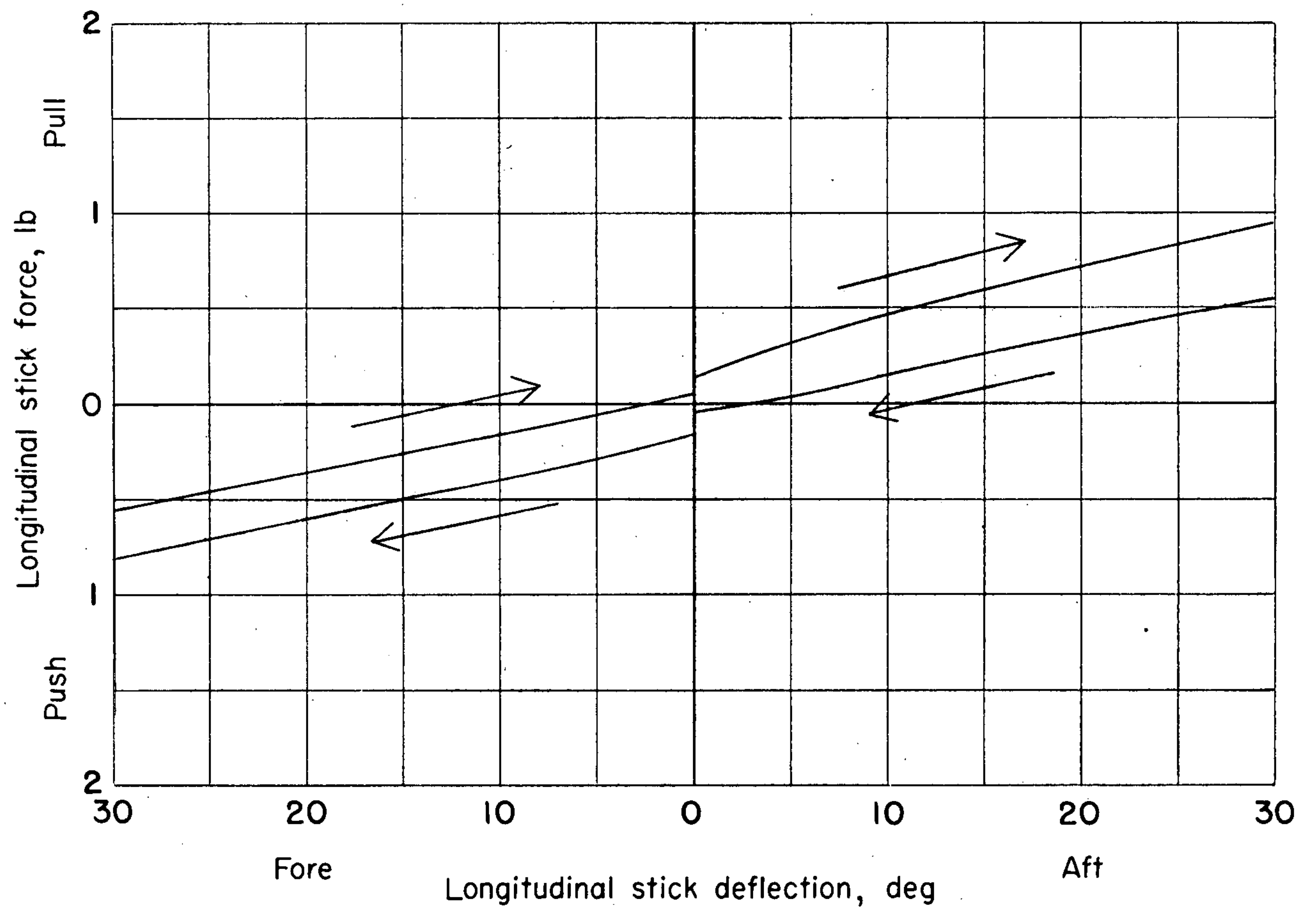
(a) View showing manner in which stick was held by pilots. L-94832.1

Figure 3.- Photographs of side-located controller.



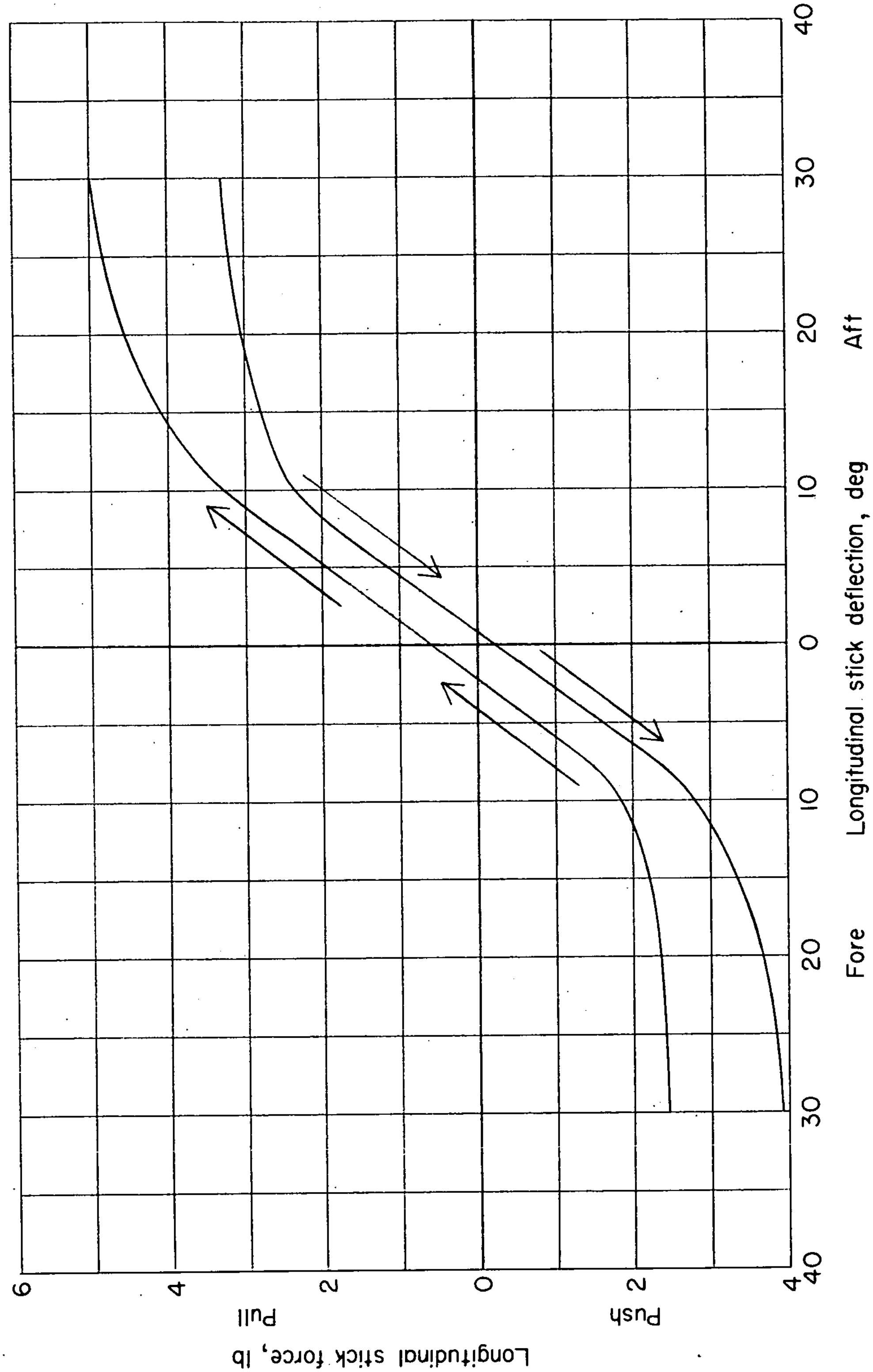
(b) View showing pitch and roll trim controls. L-95755

Figure 3.- Concluded.



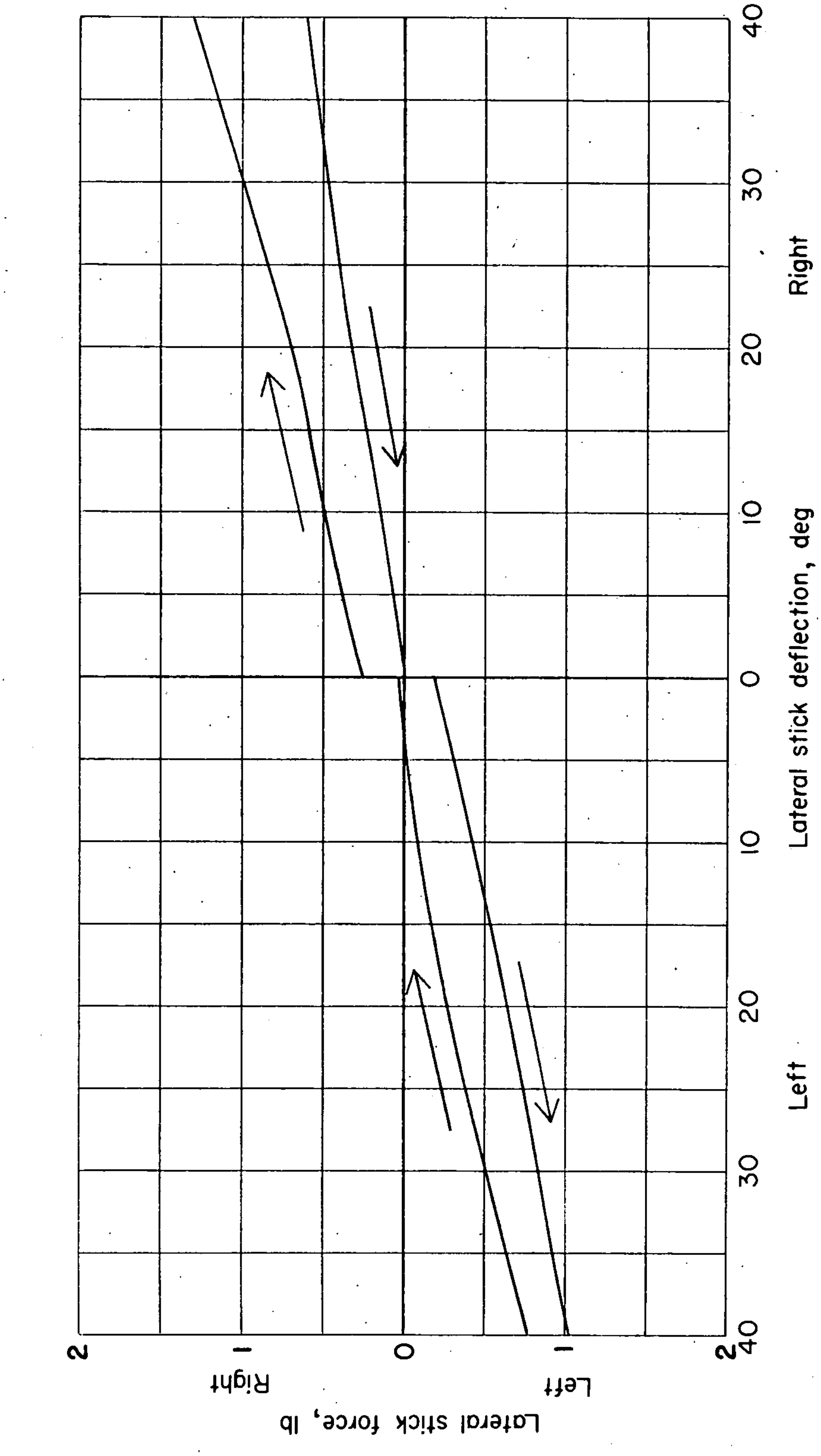
(a) Light spring.

Figure 4.- Variation of longitudinal stick force with deflection for two springs. Force is based on 2.75-inch moment arm.



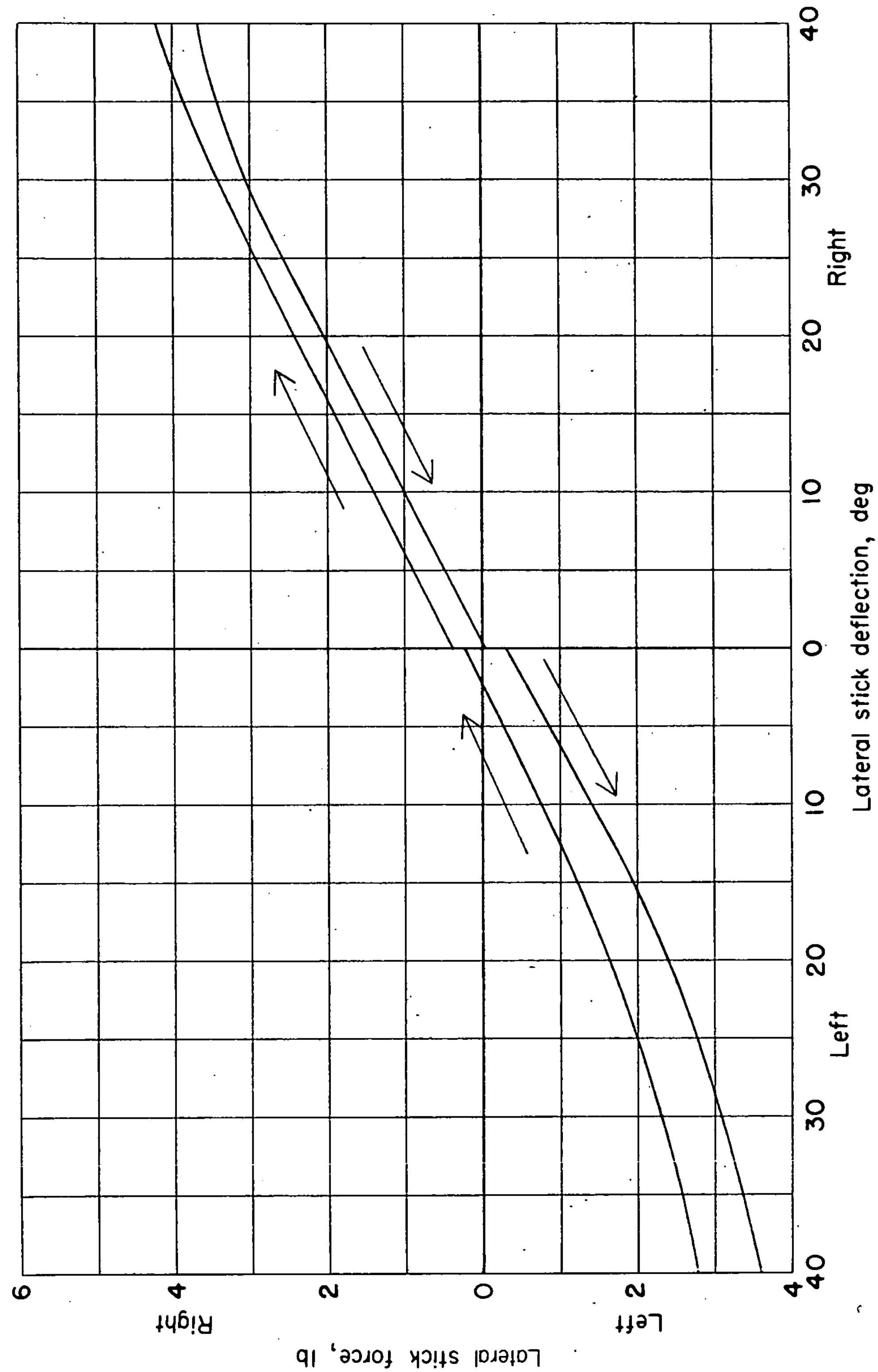
(b) Heavy spring.

Figure 4.- Concluded.



(a) Light spring.

Figure 5.- Variation of lateral stick force with deflection for two springs. Force is based on 2.75-inch moment arm.



(b) Heavy spring.

Figure 5.- Concluded.

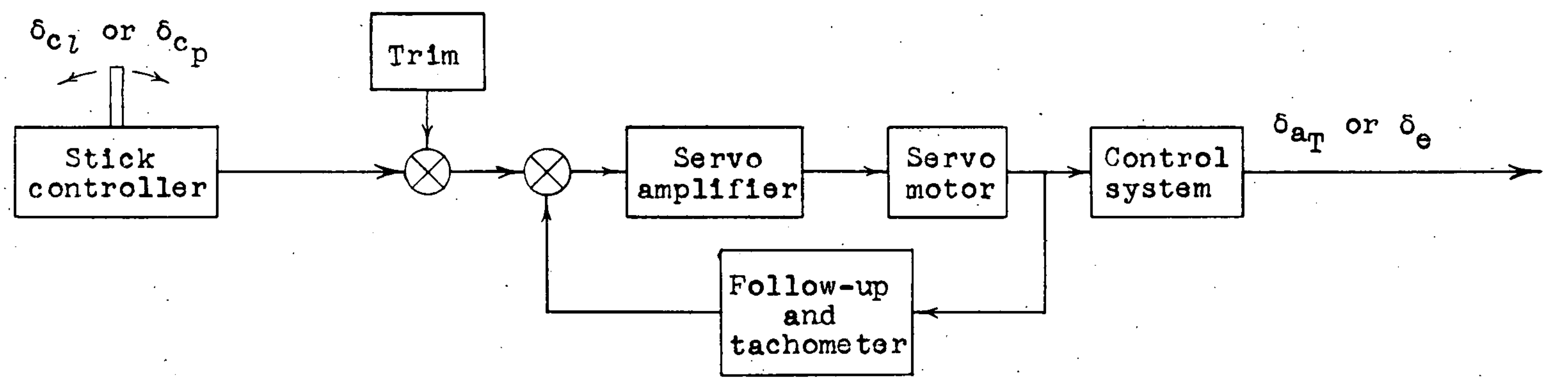
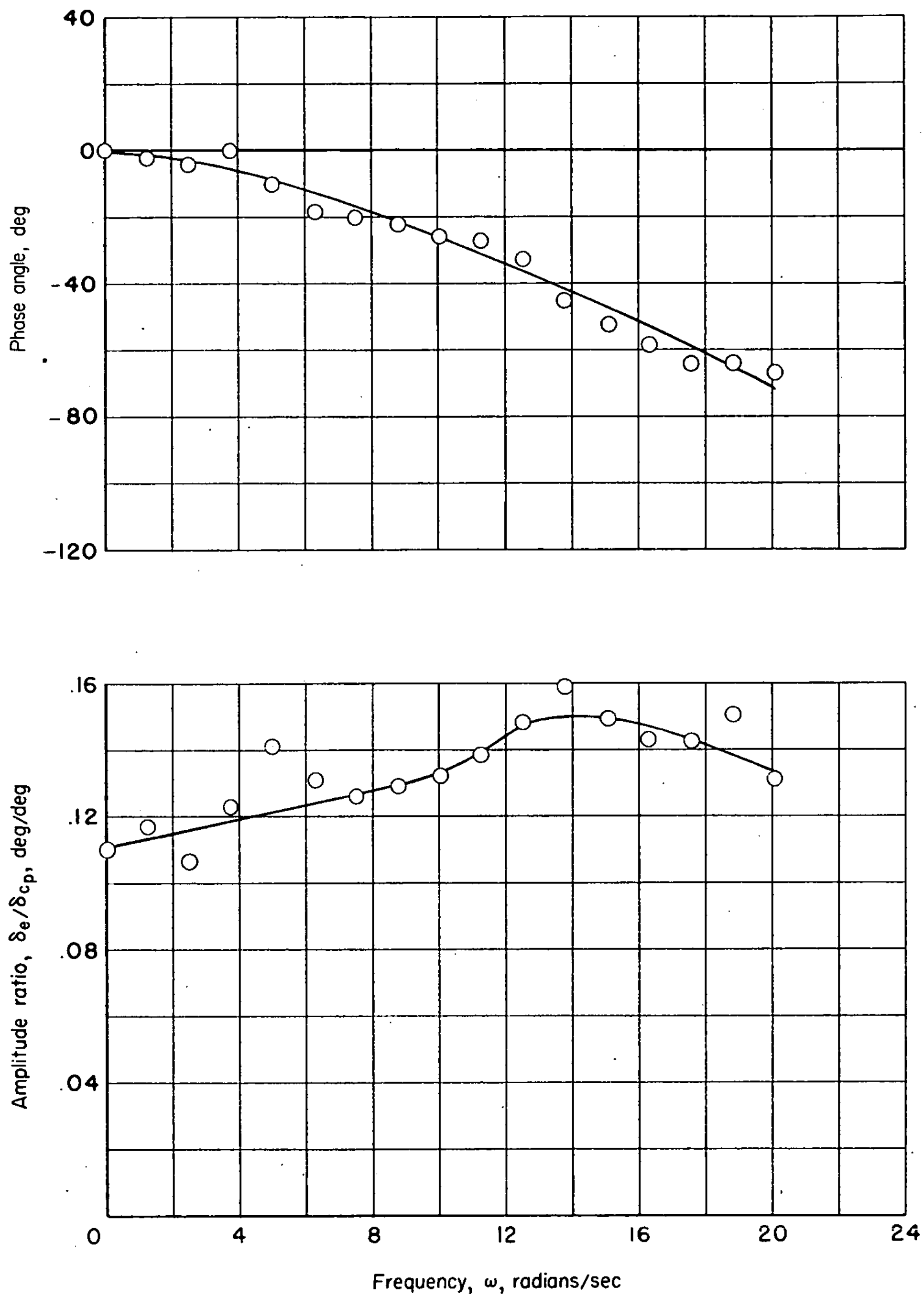
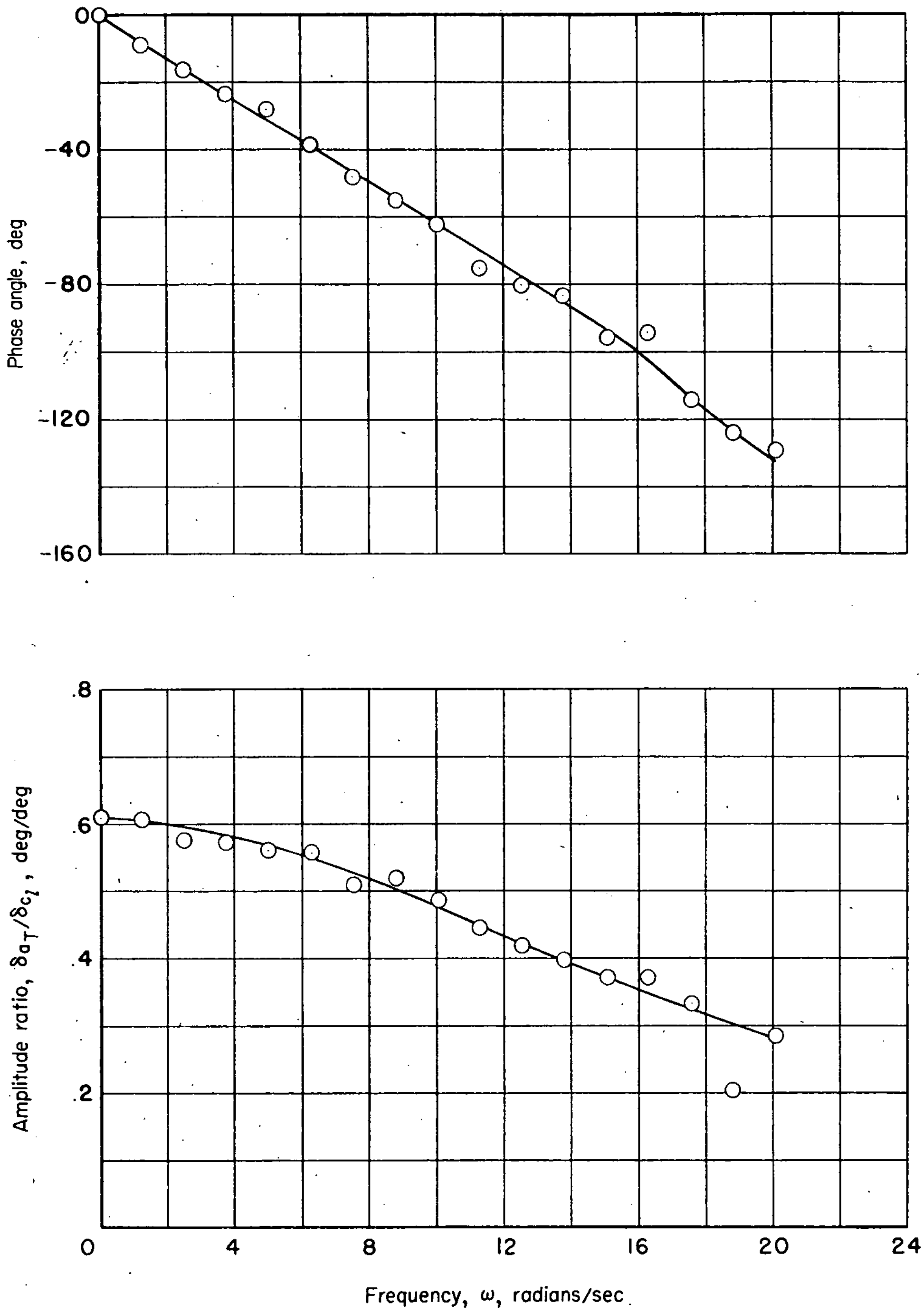


Figure 6.- Block diagram of elevator or aileron irreversible power control system.



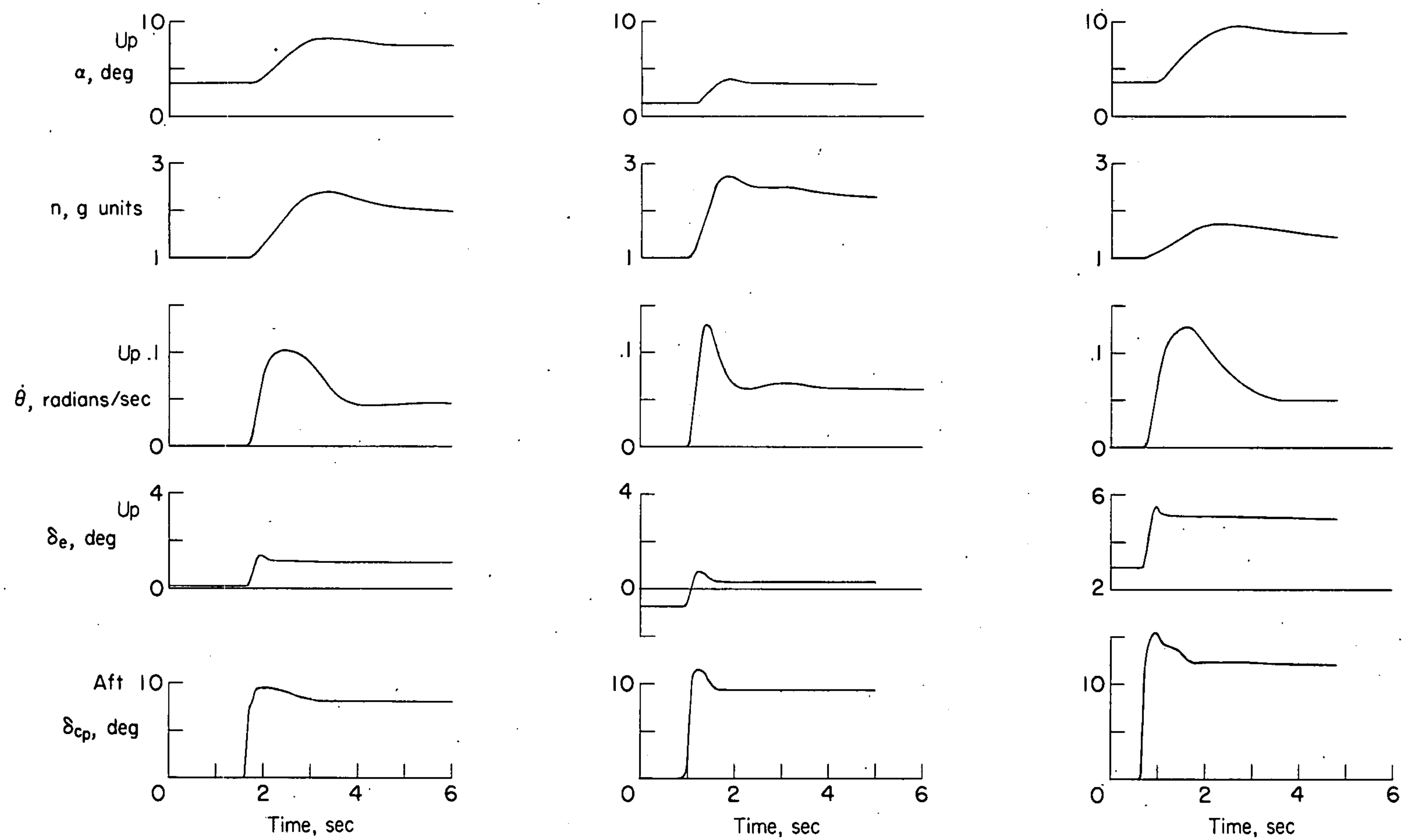
(a) Elevator system.

Figure 7.- Frequency responses of power control system. M = 0.6; h_p = 10,000 feet.



(b) Aileron system.

Figure 7.- Concluded.

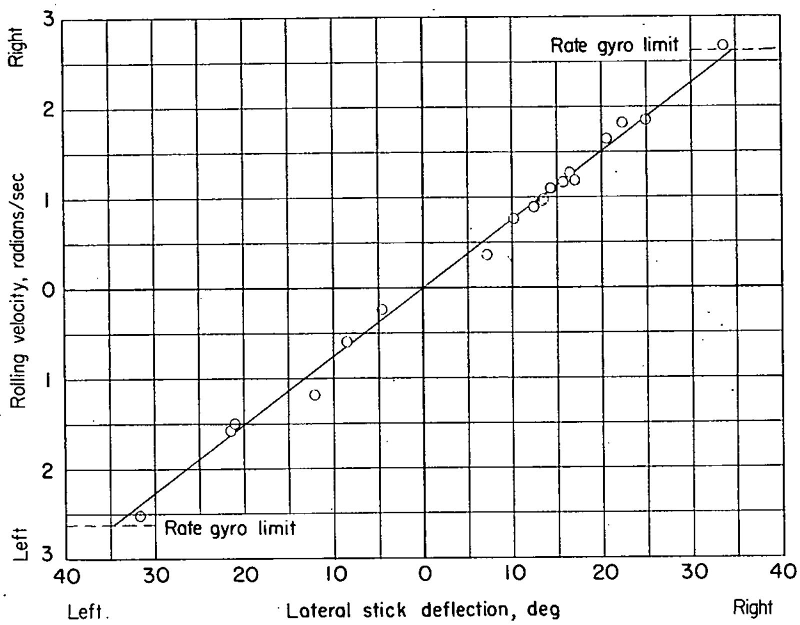


(a) $M = 0.6$; $h_p = 30,000$ ft.

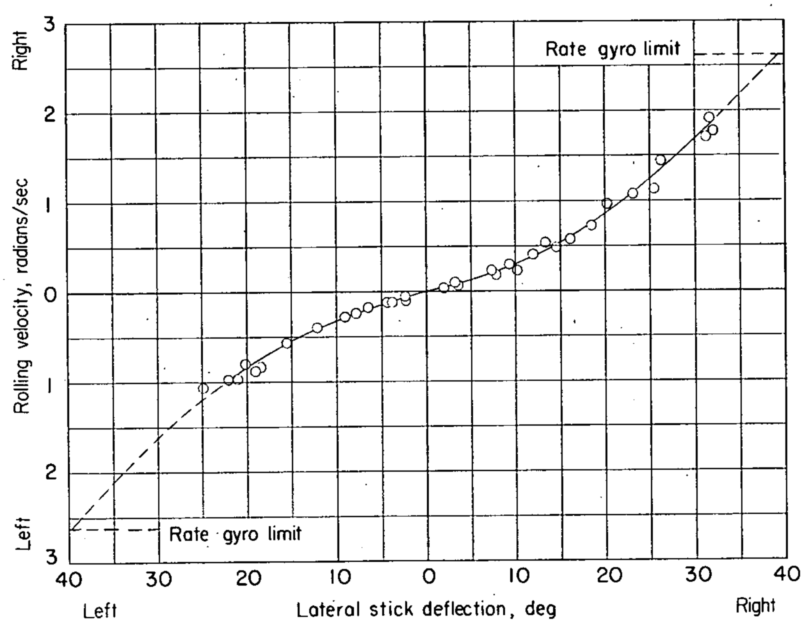
(b) $M = 0.6$; $h_p = 11,000$ ft.

(c) $V_i = 150$ knots; $h_p = 11,000$ ft.

Figure 8.- Time histories of rapid pull-up with irreversible power control system.



(a) Linear system.



(b) Nonlinear system.

Figure 9.- Variation of rolling velocity with lateral stick deflection. Rate control system; M = 0.6.

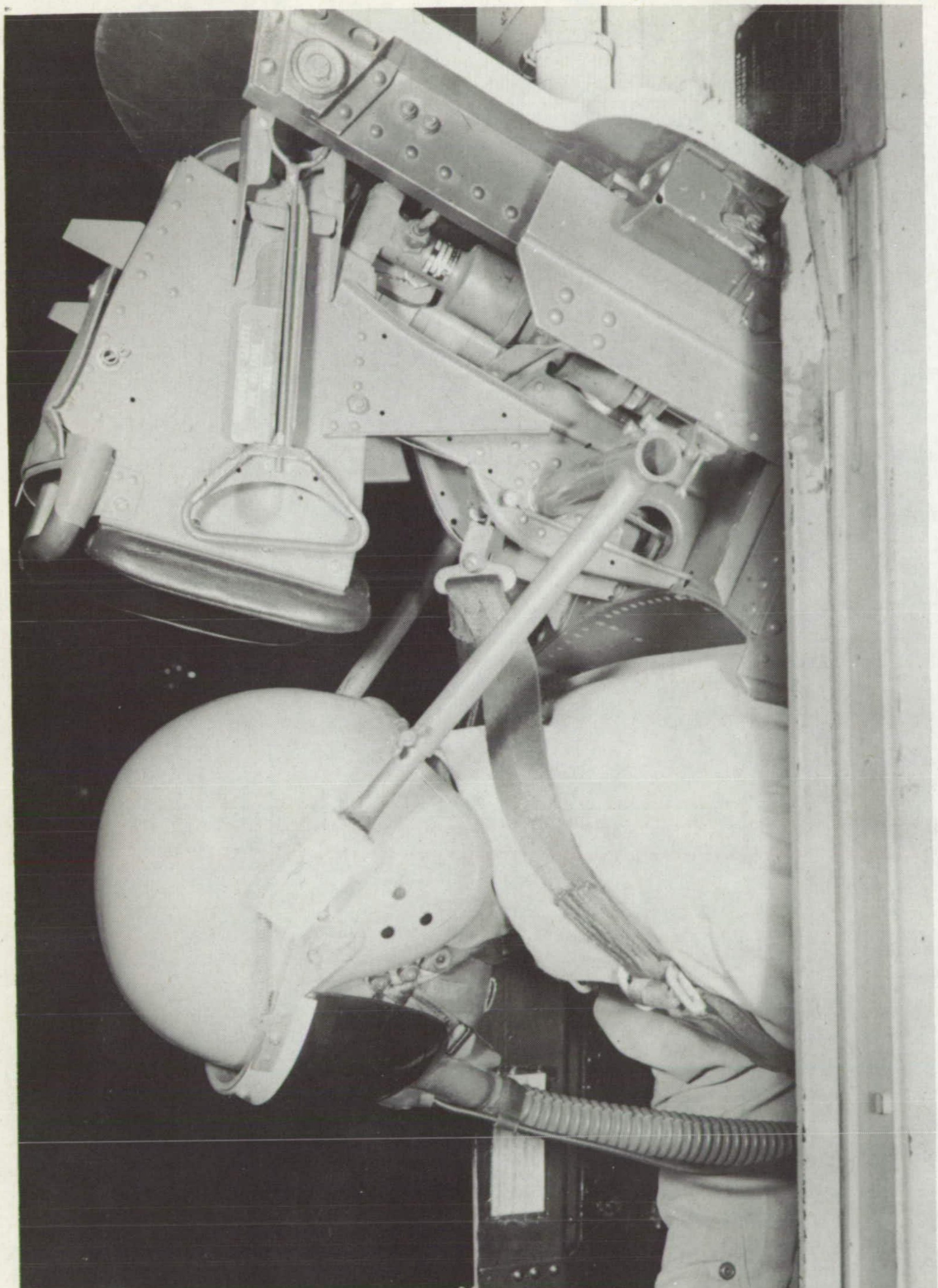
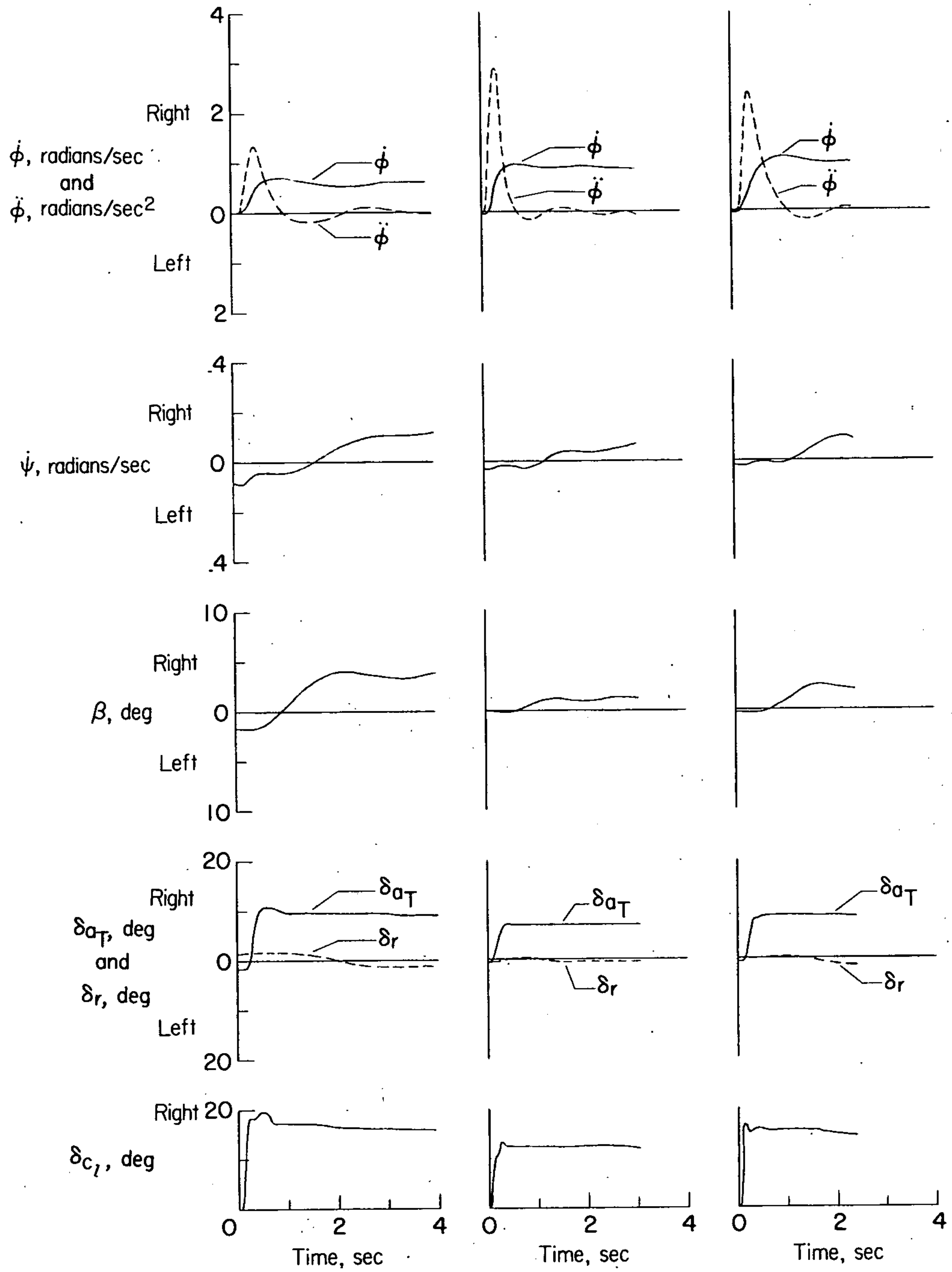


Figure 10.- Photograph of head support used to restrain pilot's head laterally. L-94830



(a) V_i = 150 knots; h_p = 10,000 ft. (b) M = 0.6; h_p = 10,000 ft. (c) M = 0.6; h_p = 30,000 ft.

Figure 11.- Time histories of roll response with irreversible power control system.

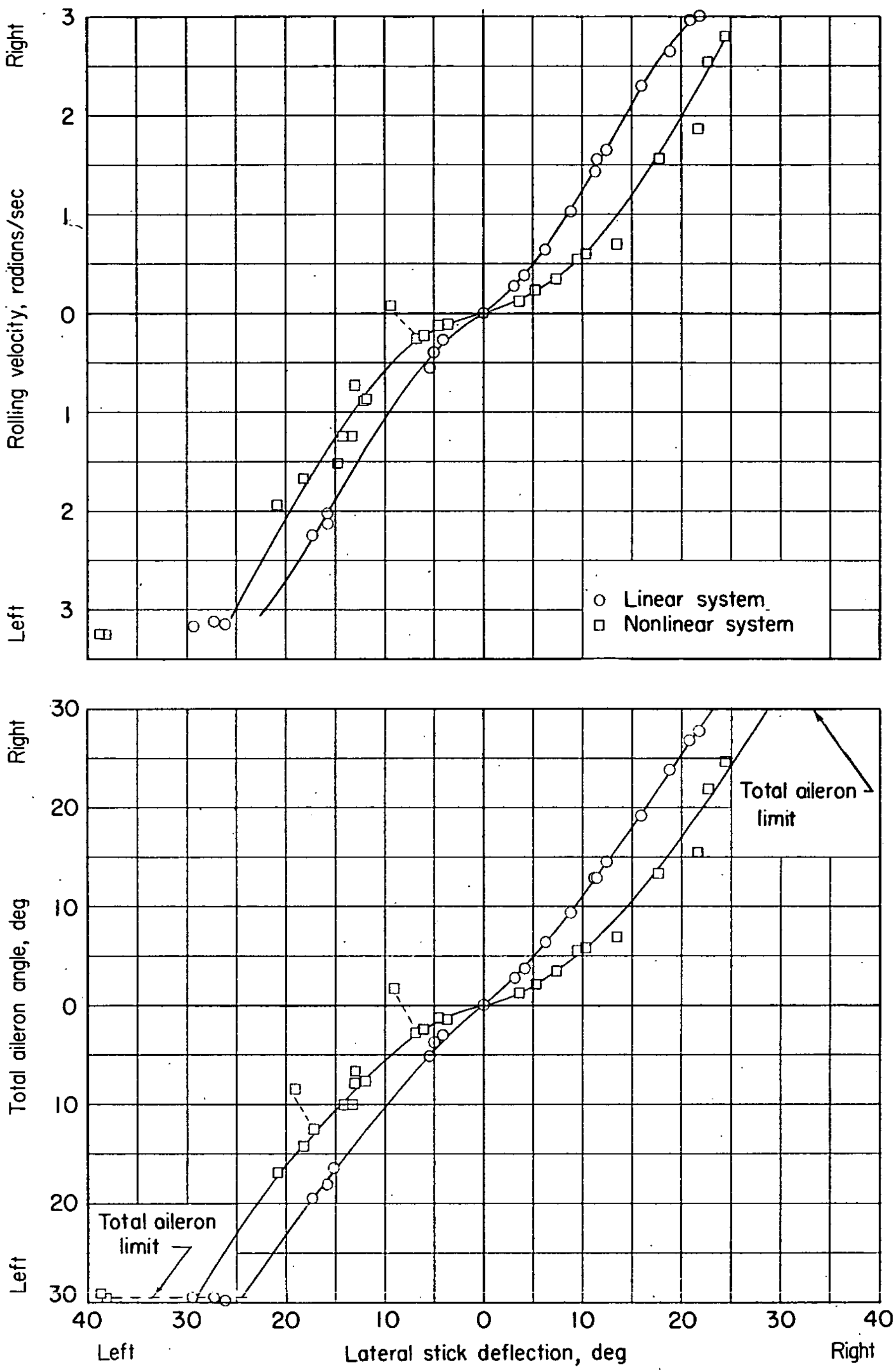


Figure 12.- Variation of total aileron deflection and rolling velocity with lateral stick deflection. Irreversible power control system; $M = 0.6$; $h_p = 10{,}000$ feet.